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AN ASSESSMENT OF MERCURY LEVELS FOUND IN SEDIMENTS AND VASCULAR PLANTS WITHIN THE SQUAMISH ESTUARY

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1.0 INTRODUCTION

The Squamish River delta is occupied by large expanses of intertidal brackish marshes which are dominated by a single species, Carex lyngbyei. Productivity estimates of these marshes were conducted in 1972 and 1974, but no further studies of these marshes have been undertaken. The high annual productivity of these marshes makes them extremely important in various food webs involving fish, birds, and mammals. Shoots of Carex lyngbyei are fed upon by muskrats and waterfowl. The seeds of this plant are one of the most important foods of a variety of waterfowl. Its roots and rhizomes are fed upon to a lesser extent. During the fall and winter, the decaying aboveground plant components are broken down by bacteria. This detritus is fed upon by a variety of invertebrates which in turn provide food for estuarine fish.

The Squamish River estuary has been the recipient of mercury contaminated discharge water from F.M.C. of Canada Ltd. for a number of years. Prior to 1970, F.M.C. discharged at least 9000 g of mercury per day, but in recent years the discharge has been reduced to 50 to 60 g per day (F.M.C. pers. comm.). Despite the drastic reduction in the quantity of mercury discharged, sampling has indicated that sediment mercury levels in the vicinity of F.M.C. still remain high in relation to background levels (Garret et al. 1980).

The accumulation of mercury within intertidal plants has not been investigated on the Pacific coast or for the plant species found in the local marshes. For terrestrial plants, it has been shown that some plants may accumulate mercury to levels greater than that found in the soil (Warren et al. 1976). Similarly aquatic plants absorb mercury directly from the water column and may concentrate the mercury to levels greater than that of the water (Garrett et al. 1980). In the eastern United States, Spartina alterniflora, the ecological equivalent of the local Carex lyngbyei has been the subject of numerous investigations. These have concluded that this species is capable of concentrating mercury in the plant roots to higher levels than were found in the sediments.

The present study was initiated to investigate the mercury levels found in the intertidal marsh areas of Squamish. In particular, the objectives of the study were to evaluate mercury levels within the vascular plant components and to determine the possible ecosystem effects.

2.0 METHODS

On July 10 - 12 1984, 50 vegetation and sediment samples were collected at various locations of the Squamish estuary (Figure 1) for subsequent mercury analyses. Aboveground vegetation samples were obtained by clipping all of the rooted plant material within a single ($0.25m^2$) quadrat at each sampling station. The belowground component was sampled by removing a ($0.025\ m^2$) plug from one corner of the clipped quadrat. A sediment sample was obtained from the rhizome depth at each site for nutrient, mercury, and particle size analysis. Information regarding plant species composition, location comments and an interstitial pH measurement were recorded at each site.

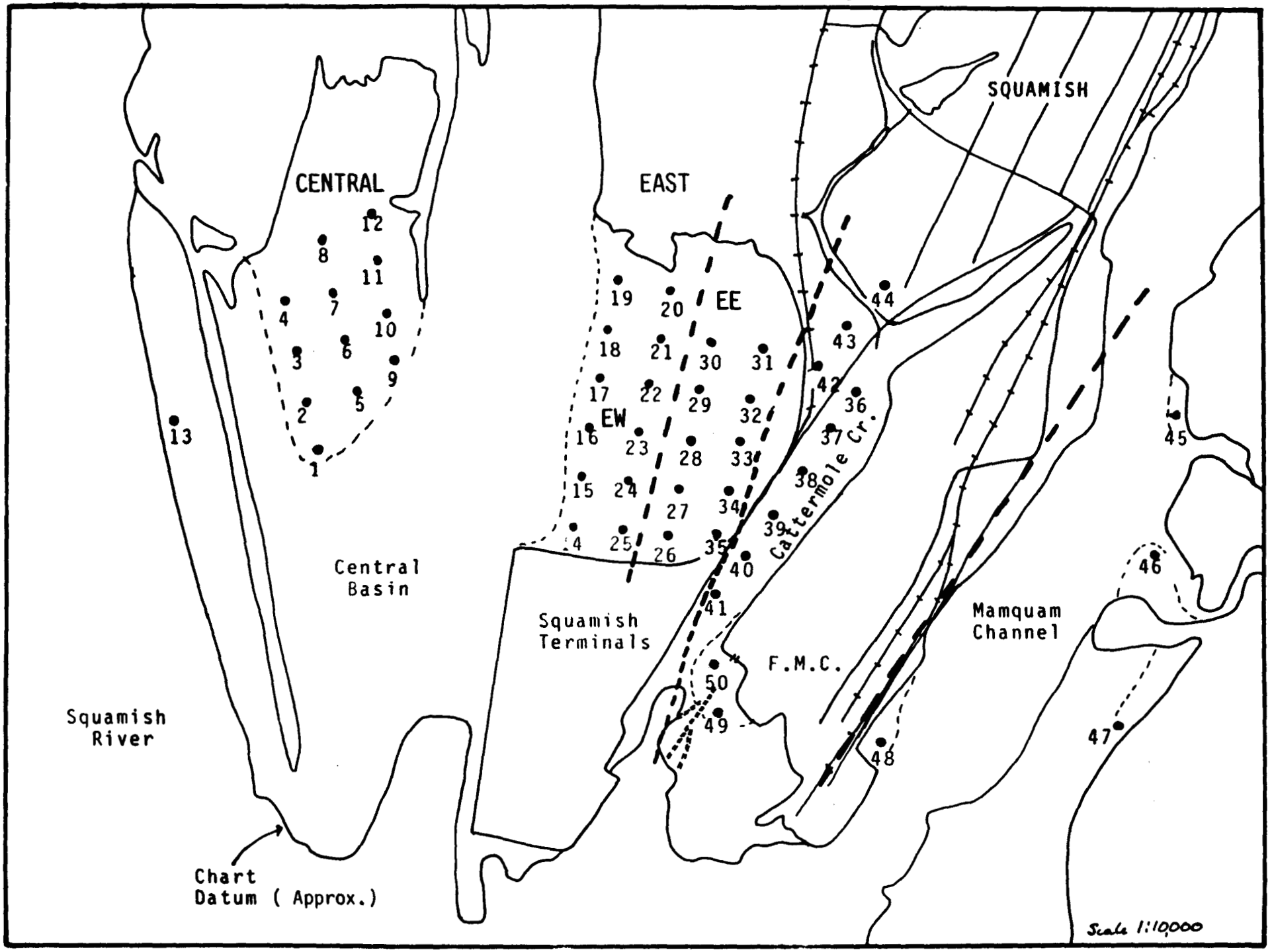
The sampling sites were established at 100 m intervals along a grid system within those areas of the delta marshes occupied by Carex lyngbyei. In some areas where only small patches of marsh occurred, a single station was sampled.

After collection the aboveground vegetation samples were subsampled for mercury analyses. Subsamples were taken from the seed, leaf, and stem components. Fresh weights of the subsamples were recorded and the subsamples were packed in dry ice for shipment to the laboratory. To ensure consistency of results, only one species (Carex lyngbyei) which occurred at all the stations sampled, was subsampled. Any other species present were identified and weighed. The remaining aboveground components were reserved for biomass determinations. Plant samples were not washed prior to mercury or biomass determinations.

The belowground plant components were separated from the sediments by washing and then segregated into root and rhizome components for mercury analyses.

Laboratory analyses for mercury, trace metals, nutrients, particle size of sediments and biomass were carried out by E.P.S. according to methods described in Swingle and Davidson (1979).

FIGURE 1: SAMPLING LOCATIONS IN THE SQUAMISH ESTUARY, B.C.



3.0 RESULTS

3.1 Biomass

Since the prime objective of this study was to evaluate the distribution of mercury in the vegetation of the Squamish estuary marshes, replication of samples was sacrificed to allow for a greater number of sampling sites. The aboveground standing crop of vascular plants showed considerable variation with values ranging from 429-1607 g/m^2 (Table 1). A comparison of the standing crop between the Central and East deltas as judged by a one-way analysis of variance revealed a significant difference ($F=7.00$; $df=1,26$; $p < 0.05$). The mean standing crop of the Central delta was 693 g/m^2 as opposed to 930 g/m^2 in the East delta. The highest biomass (1607 g/m^2) was obtained at station 13 on an island between the main river channel and the dyke (Figure 2). The West delta was not sampled due to the high flow conditions which made crossing the main channel hazardous.

3.2 Sediment Nutrients

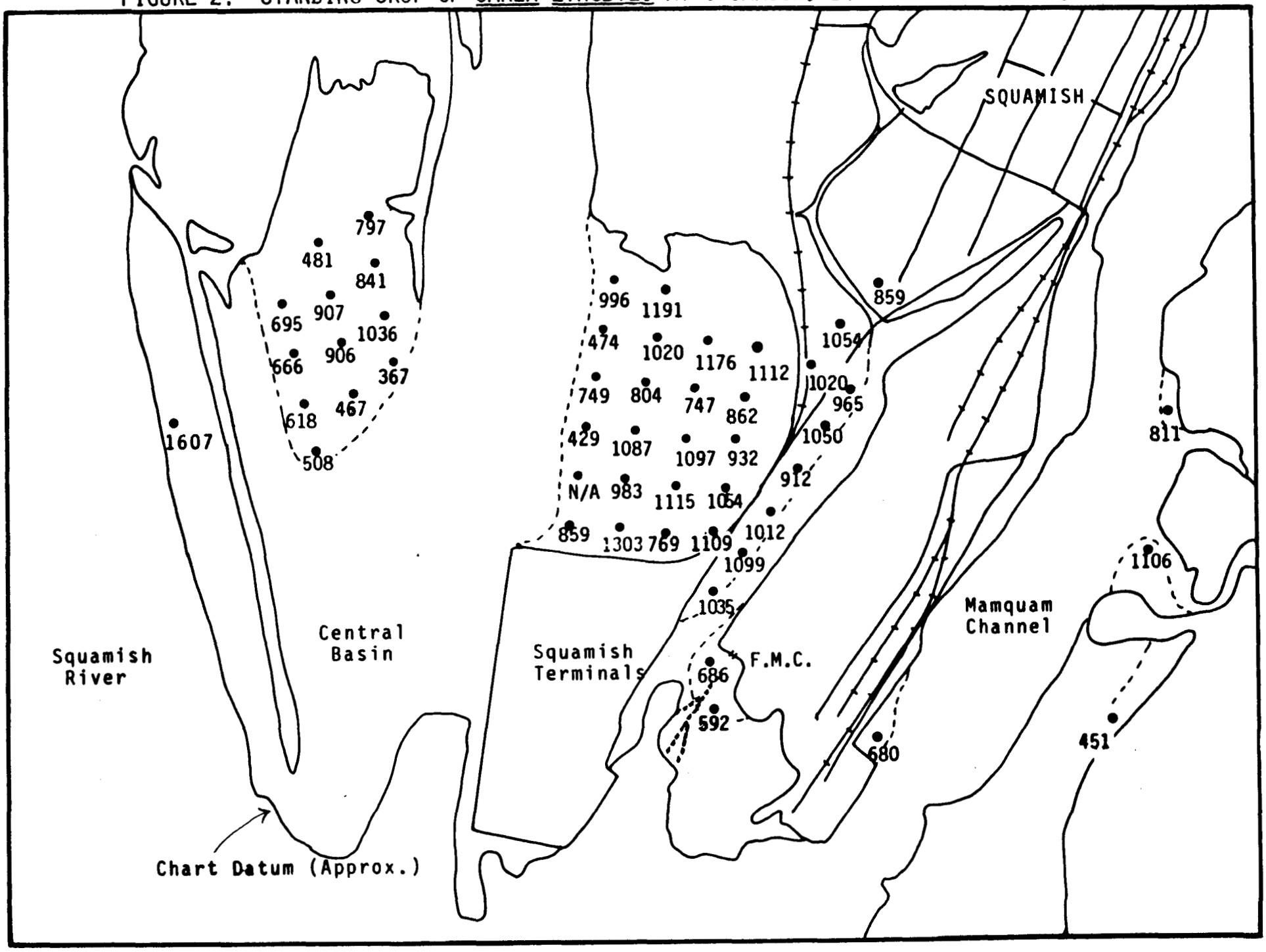
Nitrate (No_3) levels ranged between $<$ 0.4 and 2.4 mg/kg while NH_3 and PO_4 ranged from 0.28 to 14.7 and 0.86 to 13.0 mg/kg respectively. An analysis of nutrient levels (Appendix 1) and standing crop revealed no correlations. However, increases in standing crop were positively correlated ($r=0.30^*$) with increases in sediment sodium levels. Sodium levels of the sediment ranged between 1140 and 4240 µg/g (Appendix 1). The sodium levels in the underground plant components were in the order of 10 times the concentrations of the sediments.

Table 1: The Standing Crop of Intertidal Vascular Plants in the Squamish Estuary, July 10-12, 1984.

Station	Standing Crop (g/m²) [1]	Species Composition [2]	% (by weight)
1	508	Potentilla pacifica	trace
2	618	P. pacifica	trace
3	666	P. pacifica	-- 2
4	695	P. pacifica	14
5	481		
6	907	P. pacifica	4
7	906		
8	467		
9	397		
10	1036		
11	841		
12	797	Triglochin maritima	20
13	1607		
14	859		
15	lost		
16	429	P. pacifica, Triglochin maritima	55
17	749		
18	474		
19	996	P. pacifica	10
20	1191	P. pacifica	8
21	1020	P. pacifica	2
22	804	P. pacifica	1
23	1087	P. pacifica, Eleocharis palustris	48
24	983	Triglochin maritima	31
25	1303		
26	769		
27	1115		
28	1097		
29	747	P. pacifica, Triglochin maritima	5
30	1176		
31	1112		
32	862		
33	932		
34	1054		
35	1109		
36	965		
37	1050		
38	912		
39	1012		
40	1099		
41	1035		
42	1020		
43	1054		
44	859		
45	811		
46	1106		
47	451		
48	680		
49	592	P. pacifica, T. maritima	19
50	686		

1 -- dry weight of all species in quadrats converted to m²
2 -- all weights represent pure Carex lyngbyei except where noted

FIGURE 2: STANDING CROP OF CAREX LYNGBYEI AT SQUAMISH, B.C. JULY 1984. (g/m²)



3.0 RESULTS (Continued)

3.3 Sediment

The particle size analysis of the sediments from the rhizome depth did not descriminate between silts and clays (ie. < 0.063 mm). The combined silt and clay percentages ranged from 11.2 to 77.5. Although considerable variation existed between stations, some general trends were apparent. The mean silt content of the East Delta was 36%. Higher silt concentrations of close to 50% were found in the Central Delta and the Cattermole Creek areas. The lowest silt and clay values occurred in the Mamquam Channel and adjacent to the FMC outfall. The particle size analyses for all stations are presented in Appendix 3.

The pH values of the interstitial water at all sampling locations (Table 2) ranged between 5.9 and 6.8. The most common values were 6.2 to 6.3.

3.4 Mercury

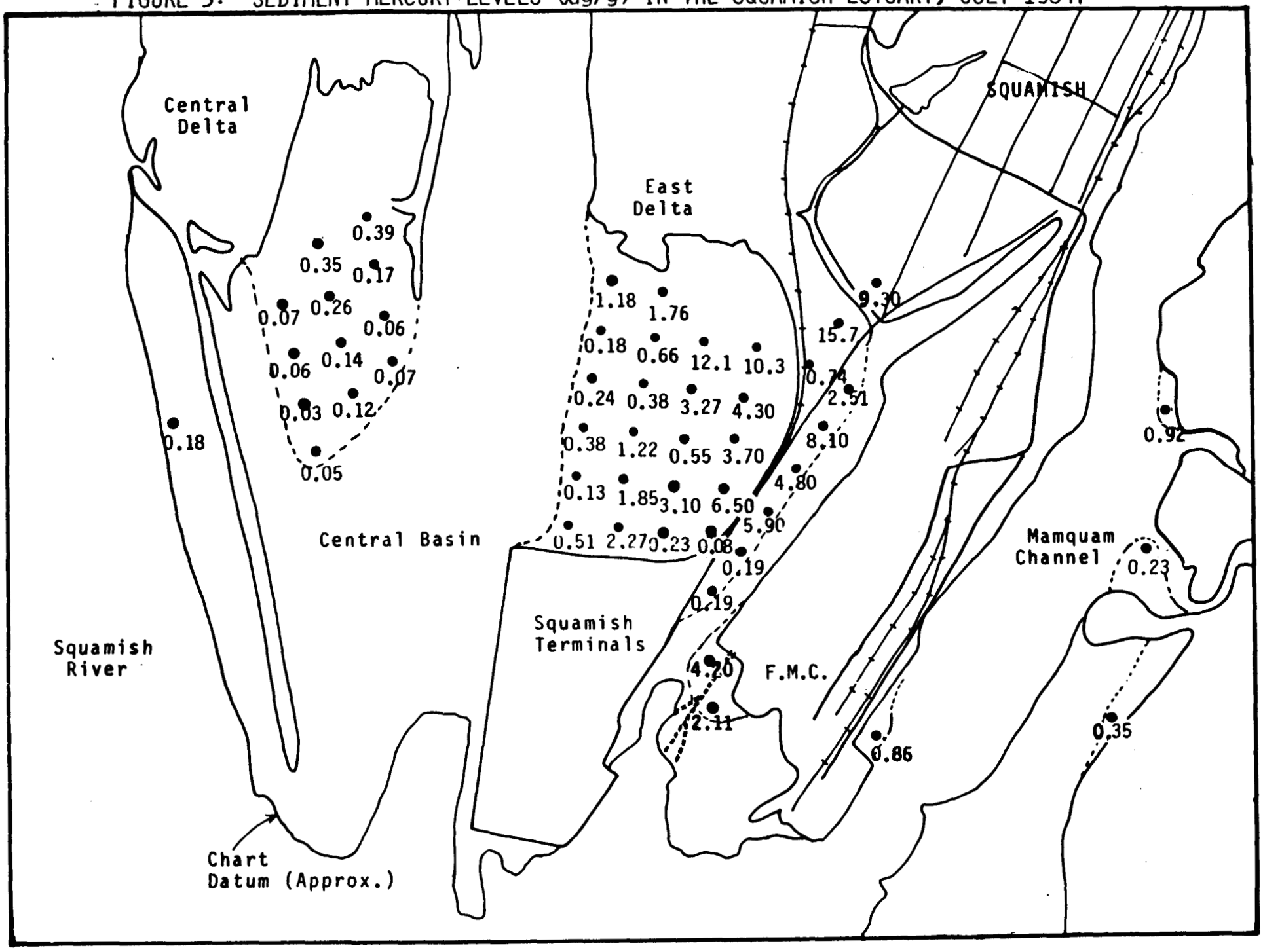
Sediments

The mercury levels found in the sediments ranged from 0.026 to 15.7 μg/g (Figure 3). These levels varied considerably from location to location. In the Central delta, mercury levels ranged between 0.026 and 0.39 μg/g with a mean of 0.14 μg/g. Slightly higher values were obtained from the Mamquam channel area where the values ranged from 0.227 to 0.86 μg/g. Low values were also obtained from those stations adjacent to those stations on the East delta which were adjacent to the Central Basin (stations 14 to 19). The low values also coincided with the major marsh channel connecting the East delta marsh to the central basin.

Table 2: Squamish Estuary Marsh Interstitial Water pH Values, July 10-12, 1984.

Station	pH
1	--
2	--
3	6.5
4	6.5
5	6.0
6	6.8
7	6.7
8	6.2
9	6.5
10	6.2
11	6.5
12	6.5
13	6.2
14	6.2
15	6.2
16	6.2
17	6.2
18	6.3
19	6.2
20	6.2
21	6.5
22	6.3
23	6.4
24	6.3
25	6.2
26	6.2
27	6.5
28	6.2
29	6.8
30	6.5
31	6.5
32	6.2
33	6.2
34	6.3
35	6.2
36	--
37	6.2
38	6.2
39	6.2
40	6.2
41	6.5
42	6.2
43	6.2
44	6.3
45	6.5
46	5.9
47	6.2
48	6.2
49	6.3
50	6.2

FIGURE 3: SEDIMENT MERCURY LEVELS (ug/g) IN THE SQUAMISH ESTUARY, JULY 1984.



3.0 RESULTS (Continued)

3.4 Mercury (Continued)

The highest mercury levels were detected in the sediments of the northeast corner of the East delta, and along Cattermole Creek (Figure 3). These values ranged up to a high of 15.7 µg/g.

The sediment mercury levels between the various deltas were significantly different as evaluated by a one-way analysis of variance ($F=4.00^*$; df= 3, 24; $p < 0.05$). Further testing by a Newman-Keuls multiple range test (Zar 1974) revealed that the mercury levels could be divided into two groups, those found on the Central and EW (western side of the East Delta) stations; and those found at the EE (eastern side of the East Delta) and Cattermole Creek stations. The Mamquam area levels were not tested owing to the limited number of samples taken. However, the sediment mercury levels from Mamquam fall within the range of those obtained from the Central and EW stations and therefore may be assumed to fall within the same group.

A weak positive correlation ($r=0.29^*$) was detected between the linear distance from F.M.C. and the mercury level of the sediments. However, the distribution of mercury in the estuary is primarily of aquatic origin and thus related to the hydrodynamics of the estuary. Therefore the mercury distribution would not be expected to follow a linear distribution.

Previous studies have demonstrated a relationship between the silt-clay fraction of sediments and mercury concentrations (Lindberg et al. 1975). Theoretically the clay platelets offer more surface area for the mercury to bond to. An evaluation of the mercury content of the sediments and the percentage of fines found during this study revealed no correlation.

3.0 RESULTS (Continued)

3.4 Mercury (Continued)

Aboveground Vegetation Component

There was little difference in mercury levels of the aboveground plant components within individual locations. The greatest range in values occurred in the leaves (0.04-0.41 µg/g) collected adjacent to Cattermole Creek (Table 3). Because of the similarity in the mercury levels of the aboveground components, these figures were pooled to provide a mean aboveground value for each station.
A one-way analysis of variance revealed highly significant differences between the four major sampling areas ($F = 11.67$; $df = 3, 24$; $p < 0.05$). Further testing using a Newman Keuls multiple range test showed that the mercury levels in the aboveground components were similar for the Central, EW and EE stations but that there was a statistically significant difference between these and the Cattermole stations. The Mamquam stations were not tested but their mean values were comparable to those of the EE stations and may therefore be assumed to fall within the Central - EE -- EW grouping.
Regression analysis of the aboveground plant component mercury levels showed a significant increase ($r = 0.42$) with increases in sediment mercury levels (Figure 4).

Belowground Vegetation Component

The range of mercury levels found in the belowground component was from below 0.02 to 7.0 µg/g for rhizomes and 0.04 to 7.9 for roots. In general, the root values slightly exceeded the rhizome values although in some cases this relationship was reversed. Calculations of root and rhizome mercury concentration ratios failed to show any consistent pattern. The root and rhizome values were pooled in order to yield a belowground value for each station.

TABLE 3: Mercury Levels (ug/g) of Sediments and Plant Components from 5 Locations in the Squamish Estuary. Sample Statistics are Mean ± Standard Deviation, with Range in Parentheses.

Location	Sediment	Rhizomes	Roots	Stems	Leaves	Seeds
CENTRAL	n = 13	n = 11	n = 11	n = 13	n = 13	n = 13
Stations 1-13	0.15 ± 0.12	0.14 ± 0.10	0.13 ± 0.11	0.07 ± 0.04	0.05 ± 0.02	0.08 ± 0.10
	(0.03 - 0.39)	(<.02 - 0.35)	(0.04 - 0.42)	(0.04 - 0.17)	(0.03 - 0.08)	(0.04 - 0.14)
EAST - EW	n = 11	n = 11	n = 11	n = 11	n = 11	n = 11
Stations 14-25	0.90 ± 0.74	0.30 ± 0.21	0.47 ± 0.29	0.04 ± 0.01	0.08 ± 0.03	0.05 ± 0.02
	(0.13 - 2.27)	(0.02 - 0.59)	(0.10 - 1.15)	(0.03 - 0.07)	(0.02 - 0.13)	(0.02 - 0.07)
EAST - EE	n = 10	n = 10	n = 10	n = 9	n = 9	n = 9
Stations 26-35	4.41 ± 4.12	1.11 ± 0.69	1.49 ± 2.02	0.06 ± 0.02	0.07 ± 0.02	0.08 ± 0.06
	(0.08 - 12.10)	(0.10 - 2.38)	(0.13 - 7.00)	(0.04 - 0.09)	(0.04 - 0.09)	(0.04 - 0.23)
CATTERMOLE	n = 11	n = 11	n = 11	n = 11	n = 11	n = 11
Stations 36-44, 49,50.	4.89 ± 4.72	1.49 ± 1.99	2.35 ± 2.36	0.14 ± 0.08	0.16 ± 0.10	0.13 ± 0.05
	(0.19 - 15.70)	(0.03 - 7.00)	(0.63 - 7.90)	(0.06 - 0.31)	(0.04 - 0.41)	(0.02 - 0.22)
MAMQUAM	n = 4	n = 4	n = 4	n = 4	n = 4	n = 2
Stations 45-48	0.59 ± 0.35	0.18 ± 0.15	0.24 ± 0.07	0.05 ± 0.04	0.07 ± 0.05	0.03 ± 0.01
	(0.23 - 0.86)	(<.03 - 0.38)	(0.15 - 0.30)	(0.02 - 0.08)	(0.02 - 0.14)	(0.02 - 0.04)

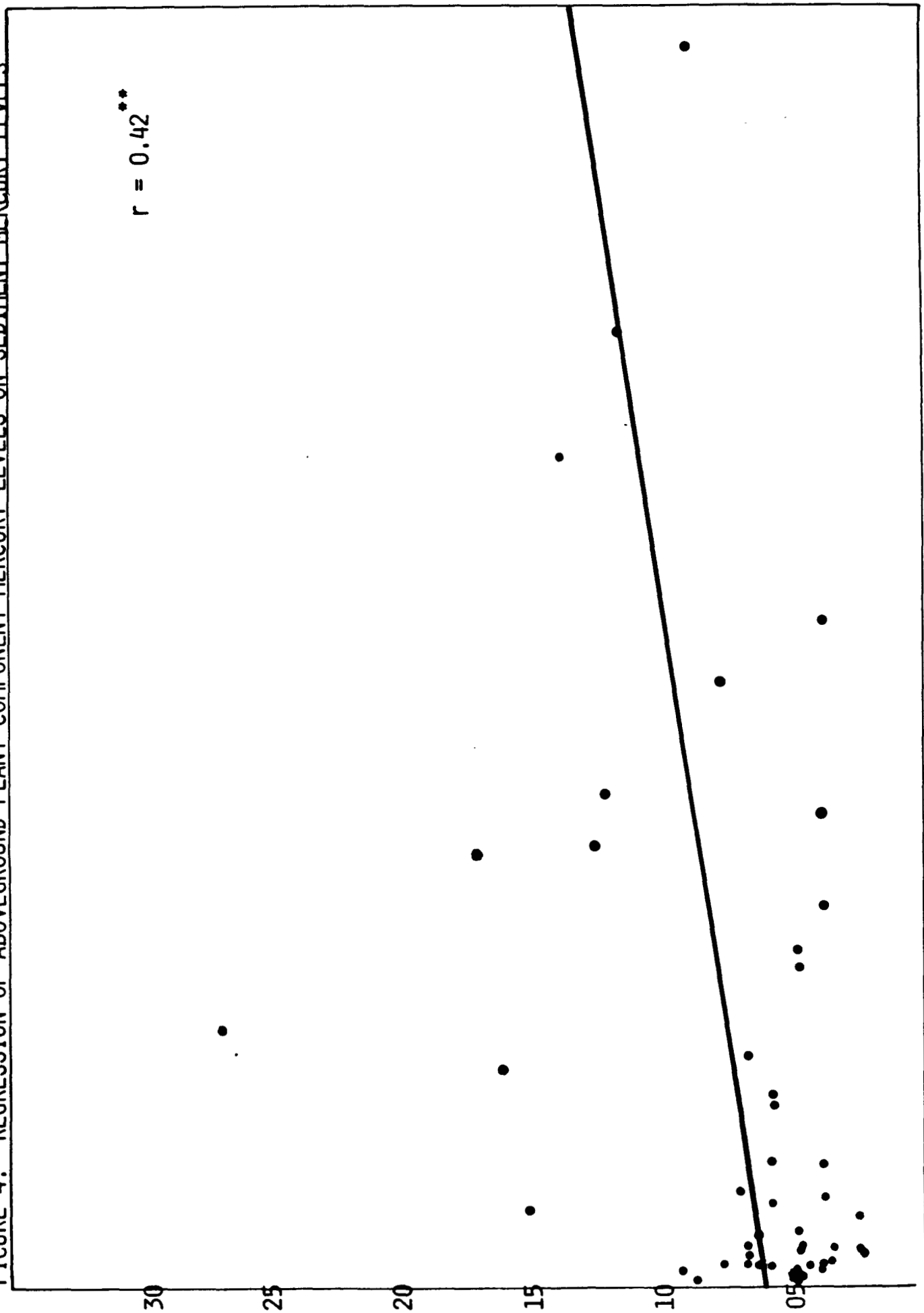


FIGURE 4: REGRESSION OF ABOVEGROUND PLANT COMPONENT MERCURY LEVELS ON SEDIMENT MERCURY LEVELS

3.0 RESULTS (Continued)

3.4 Mercury (Continued)

Regression analysis revealed a highly significant correlation ($r = 0.82^{**}$) between mercury increases in the belowground plant components and in the sediment (Figure 5). Given the amount of variability encountered in the root and rhizome data it is unclear whether any of the high mercury levels could have arisen as a consequence of sediments adhering to the plant material.

Locational effects in the belowground component were evaluated using a one-way analysis of variance. This test revealed a statistically significant difference between the delta locations ($F = 5.30^{*}$; $df = 3, 24$; $p < 0.05$). The Newman-Keul test indicated that the division was the same as that identified for the sediment mercury levels, ie. the Central and EW stations were distinct from the EE and Cattermole stations. Again, Mamquam was not tested but as before the values lay well within the range of the Central-EW group.

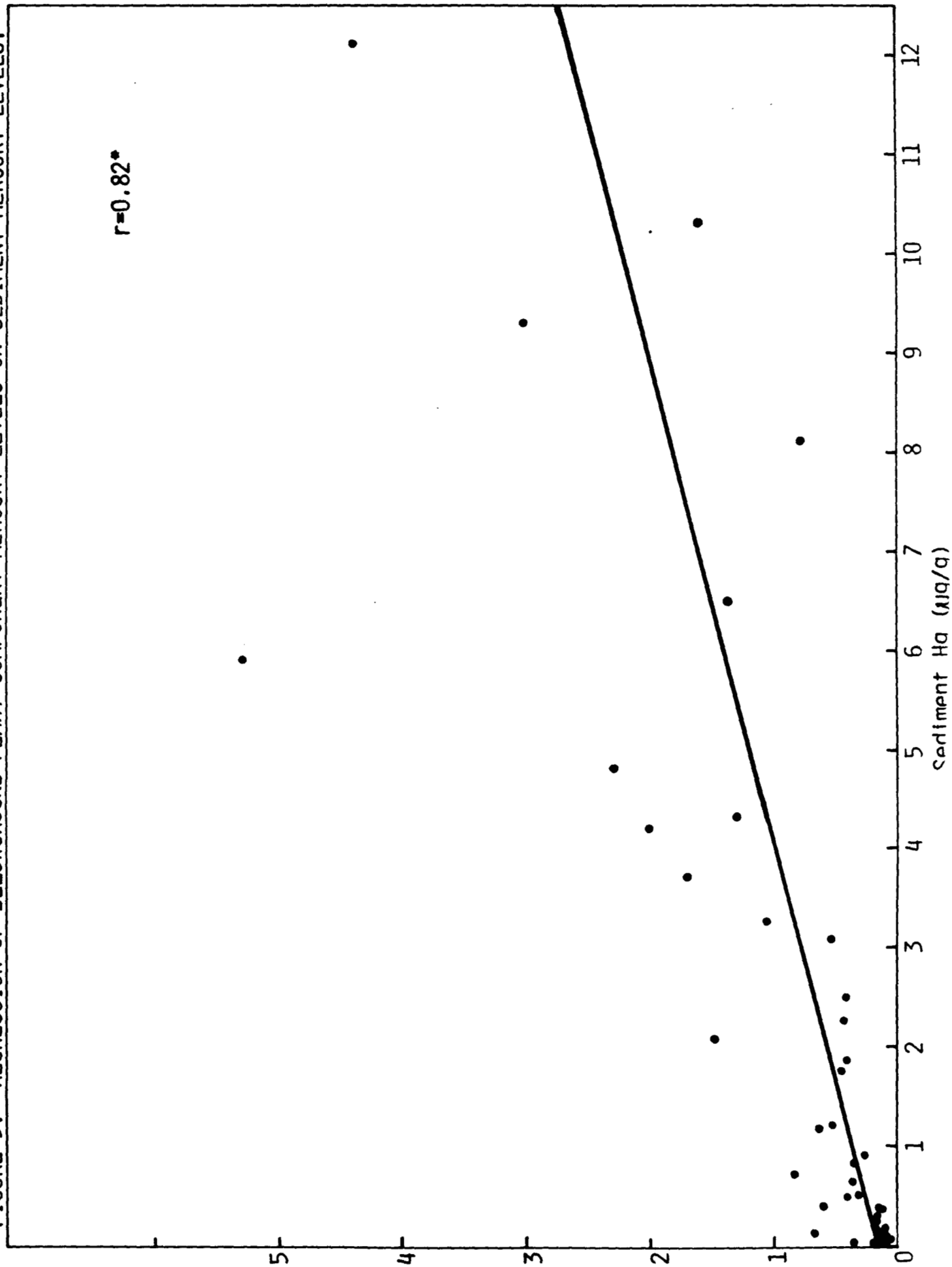


FIGURE 5: REGRESSION OF BELOWGROUND PLANT COMPONENT MERCURY LEVELS ON SEDIMENT MERCURY LEVELS.

4.0 DISCUSSION

Mercury concentrations in the sediments of the Squamish estuary ranged between 0.03 to 15.7 µg/g. The values were highly variable depending on location within the estuary. Data on mercury concentrations from other locations reported in the literature have also been quite variable but have at their upper limits been lower than those described in this study. A few of the locations sampled and their range of mercury concentrations include: San Francisco Bay, 0.02-2.00 µg/g; Mississippi River, 0.07-1.10 µg/g; and a Georgia salt marsh 0.05-3.5. Data from Bellingham Bay, which also lies adjacent to a chlor-alkali plant indicate a range of values from 0.8 to 10.7 µg/g (cited in Lindberg et al. 1975). Thus the values obtained for sediment mercury in Squamish certainly exceed many others at the upper limit of values reported. Of further concern is the fact that the mercury in marsh sediments has been shown to remain in situ for many years (Newell et al. 1982).

The distribution of mercury in the sediments of the Squamish estuary appears to be closely linked to upper Cattermole Creek. Although values adjacent to the creek were somewhat variable, the mean sediment mercury values of this area were at least 30 times that of the values from a relatively undisturbed portion of the estuary (Central Delta). The high sediment mercury values found adjacent to upper Cattermole Creek coincide with relatively high levels in the water column of this area (Pomeroy pers. comm.). These results at first glance seem somewhat perplexing in light of the much lower levels found immediately adjacent to the FMC outfall. Three possible explanations could account for this. First, since the stations reflecting the high sediment mercury levels are removed from a high energy environment and hence do not experience much erosion or deposition, these high values could reflect historical mercury levels of the estuary (ie. mercury deposited prior to FMC's reduction of discharge). The sediments collected for this study were obtained from rhizome depth (ie. 5-10 cm) and therefore reflect mercury levels which were deposited at some time in the past. Thus the greater the deposition rate within any area, the more recent the sediments which were sampled. The aboveground plant components may be more indicative of present-day mercury levels since these plant parts are directly exposed to the water carrying the mercury. However, this feature may be confounded by the translocation of mercury from the roots of the plants.

4.0 DISCUSSION (Continued)

Secondly, the two stations adjacent to the FMC outfall (49 & 50) were located on very sandy substrates with clay and silt contents amounting to less than 17%. Although there was no correlation between grain size and mercury levels found in this study, the silt-clay content of the other marsh sediments at rhizome depth was generally quite high (means 36-50%). Stations 49 and 50 show the lowest concentration of fines sampled with the exception of Station 36 on Cattermole Creek which had a mercury value of 2.5 µg/g. The third factor to consider is the hydrodynamics of the estuary. The high levels of mercury in the sediments and the water column of upper Cattermole Creek and the low levels at its mouth (Stations 40 & 41) would lead one to further examine water movements and their residence time at the various locations.

There is considerable variation in the literature regarding sediment particle size and mercury adsorption. Gardner et al. (1978) reported that Spartina alterniflora root mercury values from sites with a high sand content reached levels up to 40 times greater than those of peaty marshes. However, Houba et al. (1983, cited in Pritchard 1984) found no correlation between the fate of heavy metals and the clay content of sediments. Other studies (Lindberg et al. 1975) have indicated that the concentration of mercury in sediments is strongly associated with particulate organic matter. This is partially due to the decomposition of the aboveground plant material and the consequent concentration of the mercury which was found in the tissues. Another theory has tied in bacterial enrichment of detritus to increased mercury levels (Lindberg et al. 1975). Because of the reactivity of mercury, particulate matter in suspension strongly affects the behaviour of mercury in the water column. Much of the mercury in estuarine areas either adsorbs onto suspended sediments or precipitates in conjunction with dissolved organic matter (Lindberg et al. 1975). Some estuarine areas thus tend to accumulate more mercury than others as water flow patterns and the fresh and salt water interface dictate the precipitation of particulate matter into specific regions. Mercury has also been shown to have a strong affinity for NH_4, but this relationship needs further investigation.

The plants found on the Squamish estuary marshes, Carex lyngbyei in particular, appear to accumulate mercury in their tissues, especially in the belowground organs, but they do not seem to concentrate mercury

4.0 DISCUSSION (Continued)

to levels greater than that found in the sediment. However, this study did find a highly significant correlation between sediment mercury levels and the mercury levels within the belowground plant components. A less dramatic relationship was observed between the aboveground component mercury levels and those of the sediments. Mercury can also be taken into the plant as a consequence of aerial deposition or through direct absorption from the water column. Since the marsh vegetation is regularly washed by tidal action it is unlikely that aerial emissions play an important role in contributing mercury to the plant. In other studies it has been found that grasses from the upper intertidal area contained significantly less mercury than those from the lower intertidal (Windom et al. 1976). Studies from Spartina alterniflora marshes have also shown that mercury is concentrated in the belowground organs and that these values tend to reflect the concentration of mercury in the sediments (Breteler et al. 1981). All of the plant parts showed an increase in mercury as the mercury levels rose in the sediments, however the roots showed the steepest increases in relation to increased sediment mercury (Gardner et al. 1978). The translocation of mercury to the above-ground components appears to be limited by some form of blocking mechanism (Beauford et al. 1977). In laboratory conditions, hydroponically grown Spartina alterniflora transferred 1% of the mercury from its roots to its leaves and 3% to the culms (Rahn 1973). Other studies have reported that leaf tissue concentrations were either four times greater than those of the culms (Breteler et al. 1981) or the leaves and culms have been reported as being approximately equal (Gardner et al. 1978).

The results of this study have revealed that although there is no constant relationship between the mercury concentrations in sediments and aboveground plant components, the aboveground values certainly increase in response to increases in sediment mercury. The belowground values are even more sensitive in response to elevated sediment mercury values. These factors have important implications for food chain relationships, in particular those based on the detrital pathway.

4.0 DISCUSSION (Continued)

Most of the annual aboveground plant production breaks down at the end of the growing season and becomes part of the detrital food web. Since we have the standing crop figures and mercury concentrations for the aboveground component, it would be possible to calculate an annual mercury release into the estuary as channeled through the vascular plants in the different parts of the estuary. Due to the high affinity of mercury for organic particulates, it is likely that this detritus could become further concentrated with mercury from the water column. Thus the vegetation may in part serve as a mercury pump, drawing it from the deeper sediments and releasing it into the estuary. Despite our findings that mercury is not being concentrated by the plants, the plants may play an important role in recycling mercury from the sediments. This factor may be particularly important if the deeper sediments have higher mercury values than the surface layers as a function of the former high mercury discharges into the estuary.

Although the aboveground plant components were low in mercury in comparison to the belowground components, in the Cattermole Creek area, the leaf mercury levels reached values as high as 0.41 µg/g. The U.S. Environmental Protection Agency has recommended a maximum tissue concentration of 1 µg/g for the protection of wildlife and 0.5 µg/g for human consumption. Two laboratory studies have reported on the effects of mercury on birds. Mallards which were fed diets containing mercury at a level of 3 µg/g had lowered hatching survival (Heinz 1974). Similarly, Japanese quail fed a diet containing 1 µg/g of mercury showed egg shell thinning (Stoewsand et al. 1971). It appears that the mercury levels detected in the aboveground components of Carex lyngbyei are below government recommended levels and below the levels determined to be harmful to some birds. However, some of the higher levels detected in the plants do approach the hazardous levels. The belowground plant component mercury levels certainly exceed the recommended levels in many cases. At present the greatest cause for concern appears to lie in the detrital food web.

5.0 RECOMMENDATIONS

The present study has revealed some of the relationships existing between plants, sediments and mercury in the Squamish estuary. However, it has also identified areas where there is insufficient information to draw firm conclusions. In order to clarify some of the relationships found in the course of this study it is recommended that some further studies be pursued.

This study only examined the plants, sediments and their mercury levels at one instance in time. Since the chemical make-up of plants varies considerably according to their phenology, it is suggested that the plants be examined at different stages in their annual cycle. In particular, mercury levels should be assessed in the young shoots starting to elongate in the spring, and in the decomposing shoots in the fall. Since Carex lyngbyei overwinters with the next years shoots protruding from the sediment, it is possible that the long exposure of these shoots to the organics on the marsh surface and the mercury in the water column, may cause them to accumulate high mercury values. These young shoots are favored by waterfowl in the spring. Decaying vegetation in the fall has also had a long exposure to mercury in the ambient waters. It has also been identified in the literature as a probable area for the concentration of mercury.

In order to evaluate the possible stores of mercury which may be tapped by the plants, it is recommended that sediment cores be examined to evaluate mercury concentrations according to depth. In conjunction with the examination of the sediment layers it would be adviseable to assess particle sizes and organic content to evaluate any possible relationships.

Since the plants and sediments both showed elevated mercury levels in upper Cattermole Creek it is recommended that water samples be taken at various locations in the creek during several tidal stages to determine what effect water movements may have on mercury concentrations in this area.

6.0 SUMMARY

Mercury has been discharged into the Squamish estuary for approximately 25 years. The quantity of mercury discharged has decreased from a level of 9000 g/day prior to 1970 to a 1984 level of 50-60 g/day.

Although marsh plants are vital components of the estuarine food web, mercury accumulations within Pacific coast estuarine plants have never before been investigated. In July of 1984, 50 stations across the Squamish estuary were sampled to determine mercury concentrations in both sediments and plants. The sampling of plants was limited to a single species, Carex lyngbyei. The biomass of this species during the sampling period ranged from 429 - 1607 g/m^2 (aboveground only).

The mercury levels of the sediments obtained from the rhizome depth (5 - 10 cm) ranged from 0.03 to 15.7 μg/g. These mercury values were statistically separable into two groups. In general, low values were found in the stations on the Central, Mamquam, and western portion of the East deltas. High values were found on the eastern side of the East Delta and adjacent to Cattermole Creek. No correlation was found between the mercury content of the sediments and the percentage of fines in the substrate.

The plants accumulate mercury in their tissues but were not found to concentrate it to levels greater than that found in the sediment. However, the vegetation may serve to draw mercury from the deeper sediment layers which reflect historical contaminant levels, and release it to the estuary through the detrital food web. Although there was no constant relationship between aboveground and belowground plant parts, the mercury levels within both components were significantly correlated with the sediment mercury levels. Mercury levels ranged between 0.02 μg/g to 7.0 μg/g for rhizomes and 0.04 to 7.9 μg/g for roots. The highest aboveground plant component mercury levels were found in leaves (0.41 μg/g) in the Cattermole Creek area.

6.0 SUMMARY (Continued)

Mercury concentrations in all plant parts and sediments appear to be closely linked to upper Cattermole Creek. The possible reasons for this distribution were identified as follows:

1) The concentrations of mercury in the sediments and the water column of upper Cattermole Creek may be related to the hydrodynamics of the estuary.
2) The particle size of the sediments and the concentration of organics within the sediments may influence mercury deposition.
3) The patterns of mercury concentration observed may reflect historical levels of mercury deposition and the related sediment deposition patterns within the estuary. The sediments sampled were collected from the rhizome depth and therefore also reflect mercury deposited at some time in the past.

The recommendations for future work arising form this study include:

1) evaluation of the changes in sediment mercury levels with depth
2) sampling of water in upper Cattermole Creek to determine contaminant distribution in relation to tidal cycles
3) evaluation of the changes in the mercury levels of plants according to plant phenology.

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APPENDIX 1: Nutrient Levels of Marsh Sediments, Squamish Estuary, July 1984.

Station	NO_3	NH_3	PO_4	Ca	Mg	Na
		(mg/kg)			(µg/g)	
1	1.4	0.69	1.1	8780	6080	1650
2	<.5	0.90	2.2	4960	3040	1140
3	2.4	0.28	0.9	9040	7220	2660
4	<.5	0.81	1.8	7610	6070	2030
5	1.2	1.14	3.1	9490	8580	2750
6	0.4	1.05	3.2	10300	9850	3010
7	1.9	1.83	7.0	10600	9790	3000
8	1.5	0.76	1.7	9770	8830	2440
9	0.5	0.92	2.7	9570	7160	2380
10	0.4	0.73	2.5	8820	5960	2020
11	<.5	1.33	4.2	10400	9370	3030
12	<.5	0.79	2.0	11100	9990	3160
13	1.1	0.52	2.1	10500	8620	2770
14	<.4	0.79	2.1	9830	8480	2600
15	<.4	0.66	1.8	8330	5560	1760
16	<.4	1.26	3.0	7730	5820	1720
17	<.4	1.46	4.2	8350	6460	1780
18	<.5	1.15	2.1	11600	8990	2690
19	<.4	0.70	2.0	12200	10200	3050
20	0.5	0.76	1.5	11900	9400	3010
21	<.4	6.80	4.8	12000	10700	3300
22	<.5	0.98	3.1	12000	10700	3070
23	0.5	1.31	1.3	10100	10000	2660
24	0.4	1.03	2.8	9730	9330	2650
25	0.6	0.66	1.9	12200	11500	3390
26	1.4	2.00	2.3	7040	6880	1740
27	0.5	3.40	2.5	9160	10500	3350
28	1.1	7.53	8.2	8880	8580	2360
29	1.4	3.90	2.2	10100	10900	2930
30	0.4	6.81	3.4	9700	11100	3210
31	1.2	2.20	11.0	10300	11000	3210
32	1.5	2.69	1.5	9890	10800	4240
33	1.3	1.35	4.1	9470	9040	2640
34	<.5	1.18	2.4	10200	10900	2830
35	<.5	0.89	3.3	6160	4710	1330
36	<.5	1.21	11.0	9400	9110	2960
37	<.5	2.04	8.4	8770	8910	2540
38	2.1	12.20	8.4	8710	8770	2170
39	1.2	14.70	7.8	10500	9770	2440
40	1.0	6.70	9.0	7370	6100	1560
41	<.5	1.32	3.7	8790	7130	1840
42	1.4	3.70	5.1	7640	5770	1840
43	<.4	2.62	2.3	10700	9250	2530
44	<.5	1.65	5.4	10200	8130	2420
45	<.5	3.40	10.0	9100	9390	2860
46	<.5	8.23	4.7	7530	10600	1660
47	0.6	0.60	2.1	6600	5270	1530
48	0.7	8.59	13.0	8650	10200	2310
49	1.5	0.37	2.2	7100	4450	1450
50	0.9	5.08	5.2	10200	8380	2630

APPENDIX 2: Mercury Concentrations Within Sediments and *Carex Lyngbyei* Components (ug/g) from the Squamish Estuary, July 1984.

Station	Seeds	Leaves	Stems	Roots	Rhizomes	Sediments
1	0.04	0.04	0.07	0.06	0.12	0.051
2	0.05	0.08	0.04	0.04	0.17	0.026
3	0.05	0.07	0.04	0.08	0.07	0.056
4	0.05	0.05	0.04	0.09*	0.30*	0.071
5	0.05	0.06	0.04	0.06*	0.05*	0.117
6	0.05	0.07	0.17	0.18*	0.10*	0.143
7	0.04	0.05	0.04	--	--	0.261
8	0.40	0.07	0.04	--	--	0.350
9	0.05	0.04	0.07	<.03	0.07	0.071
10	0.14*	0.06	0.07*	0.42	0.35	0.055
11	0.04	0.04	0.04	0.15	0.11	0.166
12	0.04	0.04	0.08	0.19*	<.02	0.390
13	0.04	0.03	0.13	0.14*	0.10*	0.183
14	0.05	0.10	0.05	0.52	0.26	0.507
15	--	--	--	--	--	0.132
16	0.07	0.11	0.04	0.10*	0.18	0.376
17	0.07	0.07	0.07	0.19	0.15	0.244
18	0.05	0.09	0.05	0.19	<.02	0.180
19	0.02	0.07*	0.04	0.62*	0.59	1.180
20	0.06	0.08	0.04	0.33*	0.58*	1.760
21	<.03	<.02	0.03	0.54	0.24	0.659
22	0.03	0.04	0.04	1.15	0.03	0.384
23	0.06*	0.07	0.05	0.06*	0.54*	1.220
24	0.04	0.10*	0.04	0.42*	0.33*	1.850
25	0.05	0.13	0.03	0.55	0.40*	2.270
26	0.10	0.09	0.04	0.17	1.31	0.229
27	0.05	0.06*	0.05	0.61	0.53*	3.100
28	0.04	0.06	0.05	0.25	0.35	0.553
29	0.05	0.07	0.04	1.15	1.00	3.270
30	0.10	0.09	0.09	7.00	1.84	12.100
31	--	--	--	0.89	2.38	10.300
32	0.23	0.09	0.09	1.67	1.01	4.300
33	0.04	0.05	0.04	1.57*	1.46*	3.700
34	0.04	0.04	0.04	1.56	1.20	6.500
35	0.08	0.06	0.06	0.13	0.10	0.077
36	0.22	0.41	0.20	0.63	0.22	2.510
37	0.14	0.18	0.11	0.92	0.66	8.100
38	0.13	0.17	0.08	2.30	2.40	4.800
39	0.07	0.09	0.09	3.20	7.00	5.900
40	0.04	0.04	0.06	0.11	0.10	0.192
41	0.08	0.08	0.08	0.12	<.03	0.194
42	0.15	0.23	0.09	1.22	1.42	0.740
43	0.13	0.21	0.11	7.90	0.29*	15.700
44	0.11	0.14	0.11	5.10	1.01	9.300
45	--	0.14	0.08	0.30	0.22	0.920
46	0.02	0.07	0.02	0.15	<.03	0.227
47	0.04	0.02	0.02	0.29	0.10*	0.349
48	--	0.04	0.08	0.22	0.38	0.860
49	0.20	0.06	0.24*	1.90	1.06*	2.110
50	0.11	0.11	0.31	2.35*	2.10	4.200

* mean of two or more replicates

APPENDIX 3: Particle Size Analysis of Sediments from the Squamish Estuary.

PARTICLE SIZING 6408-20 M1

station		01		02		03		04		05		06	
SIZE RANGE, MM		WT,G		WT,G		WT,G		WT,G		WT,G		WT,G	
)2.00		0.2	0.3%	1.8	2.4%	0.8	1.5%	7.6	11.3%	3.4	8.1%	16.1	28.3%
)1.00	(2.00	0.8	1.2%	0.7	0.9%	1.3	2.4%	1.4	2.1%	2.9	6.8%	2.6	4.6%
)0.50	(1.00	1.0	1.4%	0.9	1.2%	3.2	6.1%	3.2	4.8%	4.5	10.7%	5.0	8.8%
)0.25	(0.50	1.5	2.2%	1.6	2.1%	3.5	6.5%	3.7	5.4%	4.0	9.4%	5.0	8.8%
)0.125	(0.25	6.2	9.1%	20.9	28.1%	5.2	9.9%	4.3	6.4%	3.0	7.0%	4.0	7.0%
)0.063	(0.125	18.8	27.6%	34.7	46.6%	7.7	14.5%	10.8	16.0%	4.9	11.5%	4.1	7.2%
	(0.063	39.4	58.1%	14.0	18.7%	31.4	59.2%	36.5	54.0%	19.6	46.4%	20.1	35.3%
TOTAL WEIGHT		67.8		74.5		53.0		67.6		42.1		56.8	

		07		08		09		10		11		12	
SIZE RANGE, MM		WT,G		WT,G		WT,G		WT,G		WT,G		WT,G	
)2.00		2.4	6.4%	6.9	20.6%	2.6	4.2%	0.8	1.1%	3.4	9.9%	3.9	9.7%
)1.00	(2.00	3.3	8.9%	0.6	1.8%	0.7	1.2%	0.6	0.9%	3.6	10.6%	2.2	5.3%
)0.50	(1.00	4.0	10.8%	1.8	5.5%	1.3	2.1%	0.9	1.2%	3.7	10.9%	3.8	9.4%
)0.25	(0.50	3.7	9.9%	2.5	7.5%	2.3	3.7%	1.1	1.5%	3.0	8.7%	4.3	10.5%
)0.125	(0.25	3.5	9.3%	2.6	7.7%	2.6	4.1%	4.0	5.5%	2.3	6.7%	3.5	8.7%
)0.063	(0.125	4.3	11.5%	3.0	9.0%	4.6	7.3%	20.8	28.3%	3.0	8.7%	3.3	8.2%
	(0.063	16.2	43.2%	16.0	47.9%	48.6	77.5%	45.4	61.6%	15.2	44.4%	19.5	48.1%
TOTAL WEIGHT		37.5		33.5		62.7		73.7		34.1		40.6	

		13		14		15		16		17		18	
SIZE RANGE, MM		WT,G		WT,G		WT,G		WT,G		WT,G		WT,G	
)2.00		2.5	3.5%	6.9	11.7%	2.4	7.2%	0.4	0.4%	4.6	3.5%	1.2	1.8%
)1.00	(2.00	1.9	2.7%	2.7	4.5%	0.3	0.9%	1.5	1.2%	4.0	3.0%	2.0	3.0%
)0.50	(1.00	3.1	4.5%	4.9	8.3%	0.6	1.8%	7.1	5.8%	5.3	4.0%	4.2	6.4%
)0.25	(0.50	3.5	4.9%	10.0	16.9%	1.2	3.5%	25.1	20.6%	9.2	7.0%	5.2	7.9%
)0.125	(0.25	3.1	4.5%	10.0	16.9%	1.5	4.5%	34.5	28.4%	37.0	28.1%	8.5	12.9%
)0.063	(0.125	5.9	8.4%	8.4	14.2%	8.8	26.7%	16.4	13.4%	39.9	30.2%	11.7	17.8%
	(0.063	50.0	71.5%	16.1	27.3%	18.2	55.4%	36.8	30.2%	31.7	24.1%	33.1	50.3%
TOTAL WEIGHT		70.0		59.0		32.9		121.8		131.8		65.8	

PARTICLE SIZING 8408-25 MI

SIZE RANGE, MM		19 WT,G		20 WT,G		21 WT,G		22 WT,G		23 WT,G		24 WT,G	
)2.00		6.0	12.8%	4.5	9.9%	5.2	15.3%	8.7	19.9%	4.9	15.0%	5.8	14.1%
)1.00	(2.00	4.5	9.5%	2.4	5.2%	4.0	11.7%	3.5	8.0%	2.1	6.4%	2.4	5.8%
)0.50	(1.00	5.0	10.6%	4.2	9.2%	4.4	12.7%	5.1	11.7%	3.4	10.4%	4.1	10.1%
)0.25	(0.50	4.6	9.8%	4.4	9.7%	3.9	11.4%	4.9	11.4%	3.5	10.6%	4.1	9.9%
)0.125	(0.25	3.4	7.4%	4.1	9.1%	2.9	8.5%	3.7	8.5%	2.8	8.6%	3.2	7.9%
)0.063	(0.125	4.5	9.7%	6.3	13.8%	2.7	7.8%	3.9	9.1%	2.7	8.3%	3.2	7.7%
	(0.063	18.7	40.1%	19.6	43.1%	11.2	32.6%	13.7	31.5%	13.4	40.7%	18.2	44.5%
TOTAL WEIGHT		46.7		45.3		34.3		43.4		33.0		40.9	

SIZE RANGE, MM		25 WT,G		26 WT,G		27 WT,G		28 WT,G		29 WT,G		30 WT,G	
)2.00		14.9	36.2%	4.2	10.3%	14.2	40.9%	4.1	5.2%	5.7	11.4%	12.9	29.8%
)1.00	(2.00	2.0	5.0%	2.2	5.4%	1.0	2.7%	5.1	6.5%	2.8	5.6%	4.4	10.2%
)0.50	(1.00	3.6	8.6%	2.8	6.9%	2.1	6.0%	6.4	8.2%	5.3	10.6%	5.4	12.6%
)0.25	(0.50	4.3	10.5%	2.9	7.1%	2.7	7.7%	5.6	7.2%	5.9	11.9%	5.1	11.7%
)0.125	(0.25	3.3	7.9%	2.9	7.0%	2.6	7.3%	5.4	6.9%	4.8	9.6%	3.9	9.1%
)0.063	(0.125	3.0	7.3%	9.4	22.9%	2.5	7.3%	16.1	20.7%	4.0	8.1%	2.7	6.3%
	(0.063	10.1	24.5%	16.6	40.3%	9.8	28.1%	35.2	45.2%	21.4	42.8%	8.8	20.4%
TOTAL WEIGHT		41.2		41.1		34.8		77.8		49.9		43.3	

SIZE RANGE, MM		31 WT,G		32 WT,G		33 WT,G		34 WT,G		35 WT,G		36 WT,G	
)2.00		14.0	25.7%	4.6	12.6%	1.3	3.0%	8.1	25.2%	16.3	19.1%	15.5	32.9%
)1.00	(2.00	5.4	10.0%	2.5	6.9%	2.2	5.0%	1.4	4.3%	3.4	4.0%	5.3	11.2%
)0.50	(1.00	6.2	11.4%	3.8	10.3%	3.5	8.2%	2.9	8.9%	5.1	6.0%	5.3	11.2%
)0.25	(0.50	5.3	9.7%	4.1	11.1%	3.9	8.9%	3.4	10.5%	5.5	6.4%	5.3	11.2%
)0.125	(0.25	3.8	7.0%	3.7	9.9%	3.5	8.0%	2.7	8.5%	10.3	12.1%	5.3	11.2%
)0.063	(0.125	3.7	6.9%	3.3	8.8%	5.0	11.6%	2.3	7.2%	26.6	31.1%	5.3	11.2%
	(0.063	15.9	29.3%	14.8	40.3%	24.0	55.3%	11.4	35.4%	18.1	21.2%	5.3	11.2%
TOTAL WEIGHT		54.2		36.8		43.3		32.2		85.3		47.1	

PARTICLE SIZING 6408-25 MI

SIZE RANGE, MM		36 WT,G		37 WT,G		38 WT,G		39 WT,G		40 WT,G		41 WT,G	
)2.00		15.5	36.1%	11.4	17.1%	14.2	9.3%	4.7	6.8%	0.5	0.6%	4.2	4.1%
)1.00	(2.00	5.3	12.3%	2.1	3.1%	5.6	3.7%	2.0	2.9%	0.8	0.8%	1.5	1.5%
)0.50	(1.00	6.1	14.1%	4.3	6.5%	8.7	5.7%	3.7	5.4%	2.0	2.1%	3.7	3.6%
)0.25	(0.50	4.4	10.3%	4.2	6.4%	8.3	5.4%	4.6	6.6%	2.7	2.8%	7.7	7.5%
)0.125	(0.25	3.4	7.9%	4.4	6.6%	8.5	5.6%	4.2	6.0%	3.7	3.9%	13.0	12.7%
)0.063	(0.125	3.6	8.4%	9.4	14.2%	21.4	14.0%	6.0	8.7%	25.2	26.6%	26.1	25.4%
	(0.063	4.7	10.9%	30.6	46.1%	85.8	56.3%	44.1	63.7%	59.9	63.2%	46.5	45.2%
TOTAL WEIGHT		43.0		66.3		152.5		69.2		94.8		102.8	

SIZE RANGE, MM		42 WT,G		43 WT,G		44 WT,G		45 WT,G		46 WT,G		47 WT,G	
)2.00		6.3	9.6%	2.9	6.4%	9.6	11.4%	2.0	5.9%	0.5	0.7%	3.8	2.9%
)1.00	(2.00	1.8	2.8%	0.8	1.7%	2.7	3.2%	2.1	6.4%	0.9	1.3%	3.9	2.9%
)0.50	(1.00	4.0	6.1%	1.7	3.6%	4.8	5.7%	5.6	17.0%	1.6	2.2%	10.5	7.8%
)0.25	(0.50	4.9	7.5%	2.3	4.9%	4.9	5.8%	6.7	20.1%	3.6	5.0%	18.7	13.9%
)0.125	(0.25	8.6	13.2%	2.3	5.1%	5.7	6.8%	4.2	12.6%	16.5	22.5%	20.5	15.3%
)0.063	(0.125	17.3	26.5%	5.6	12.1%	11.9	14.1%	4.6	13.8%	25.6	35.0%	40.9	30.5%
	(0.063	22.4	34.3%	30.5	66.2%	44.8	53.0%	8.0	24.2%	24.5	33.4%	35.9	26.8%
TOTAL WEIGHT		65.3		46.1		84.5		33.1		73.2		134.2	

SIZE RANGE, MM		~48 WT,G		49 WT,G		50 WT,G	
)2.00		5.9	8.5%	4.9	4.2%	7.1	6.6%
)1.00	(2.00	2.0	3.0%	1.5	1.3%	6.5	6.0%
)0.50	(1.00	8.8	12.7%	6.8	5.8%	30.1	27.7%
)0.25	(0.50	21.0	30.3%	29.4	25.2%	30.3	27.9%
)0.125	(0.25	11.4	16.5%	36.9	31.6%	7.9	7.3%
)0.063	(0.125	6.4	9.3%	18.3	15.6%	8.5	7.8%
	(0.063	13.6	19.7%	19.0	16.3%	18.1	16.7%
TOTAL WEIGHT		69.1		116.9		108.6	